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"Defense-in-Depth" Laser Safety and the National Ignition Facility

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“Defense-in-Depth”

Laser Safety and the National Ignition Facility

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Abstract

The National Ignition Facility (NIF) is the largest and most energetic laser in the world contained in a complex the size of a football stadium. From the initial laser pulse, provided by telecommunication style infrared nanoJoule pulsed lasers, to the final 192 laser beams (1.8 Mega Joules total energy in the ultraviolet) converging on a target the size of a pencil eraser, laser safety is of paramount concern.

In addition to this, there are numerous high-powered (Class 3B and 4) diagnostic lasers in use that can potentially send their laser radiation travelling throughout the facility. With individual beam paths of up to 1500 meters and a workforce of more than one thousand, the potential for exposure is significant. Simple laser safety practices utilized in typical laser labs just don't apply. To mitigate these hazards, NIF incorporates a multi layered approach to laser safety or “Defense in Depth.”

Introduction

Most typical high-powered laser operations are contained and controlled within a single room using relatively simplistic controls to protect both the worker and the public. Laser workers are trained, use a standard operating procedure, and are required to wear Personal Protective Equipment (PPE) such as Laser Protective Eyewear (LPE) if the system is not fully enclosed. Non-workers are protected by means of posting the room with a warning sign and a flashing light. In the best of cases, a Safety Interlock System (SIS) will be employed which will “safe” the laser in the case of unauthorized access. This type of laser operation is relatively easy to employ and manage.

As the operation becomes more complex, higher levels of control are required to ensure personnel safety. Examples requiring enhanced controls are outdoor and multi-room laser operations.

At the NIF there are 192 beam lines and numerous other Class 4 diagnostic lasers that can potentially deliver their hazardous energy to locations far from the laser source. This presents a serious and complex potential hazard to personnel. Because of this, a multi-layered approach to safety is taken.

This paper presents the philosophy and approach taken at the NIF in the multi-layered “defense-in-depth” approach to laser safety.

The National Ignition Facility

The National Ignition Facility is located approximately 50 miles east of San Francisco on the campus of Lawrence Livermore National Laboratory (LLNL). It is a stadium size complex in which you could lay three football fields side-by-side. NIF is not only the largest and most energetic laser in the world, it is also the largest optical instrument ever built. There are approximately 7,500 meter sized optics and 26,000 smaller optics contained within NIF. With so many optical paths, there is plenty of potential for a laser beam to travel from one part of the facility clear across to another. This makes laser safety an extremely important and complex task.



National Ignition Facility

Derivation of Controls

Laser safety controls used at all DOE facilities are derived from individual site contracts. These contracts specify the American National Standards Institute (ANSI) Z136.1 “for the Safe Use of Lasers” as the overall governing document. At LLNL the ANSI Z136.1 is interpreted and implemented via the Institution’s Environment, Safety & Health (ES&H) Manual, Chapter 20.8, “Lasers.” From the ES&H Manual, controls are further flowed down through the site specific Operational Safety Plan (OSP). The OSP for NIF is titled “NIF Laser System Installation, Commissioning and Operation”. It spells out all of the hazards and controls contained within the NIF.

Integrated Safety Management System

The NIF utilizes the Integrated Safety Management System (ISMS) approach for all work performed. The five principles, or core functions, of ISMS are:

- Define Scope of Work
- Analyze Hazards
- Develop/Implement Controls
- Perform Work
- Feedback and Improve



ISMS Core Functions

These five principles are vital to the safe and effective implementation of all work performed. No one function is any more or less important than another. The steps taken for each principle are described in the drawing above. One step that has greatly benefited the way laser safety is implemented is the “feedback and improve” principle. New projects have greatly

benefitted from even the most minor lessons learned and best practices brought forward.

The principles of ISMS are vital in all operations performed at the NIF. Every activity goes through a detailed approval process, from the main NIF laser all the way down to smallest of tasks. Because of this process and the overall safety culture at NIF, worker safety is first and foremost in project planning. This ensures that all hazards are addressed and no question is left unanswered.

Beyond the functions of ISMS, NIF employees also live by “the Goal is ZERO.” This is a culture that has been fostered and promoted emphasizing that all accidents are preventable. Top-level management all the way down to the entry-level worker have made this their way of doing business. Safety is first and foremost in all work conducted within the NIF Directorate and every worker has the ability, authority, and responsibility to stop work if they feel it is unsafe.

At 1.8 MJ in the ultraviolet, the NIF is the most energetic laser in the world. It should be noted that during these high energy shots the NIF is considered to be a Class 1 laser system because all of the laser beams are fully contained and not accessible. The facility employs strict engineering controls (Safety Interlock System) along with full facility sweeps prior to a shot to prevent personnel exposure to any potential laser hazards, including laser-induced ionizing radiation.

Configuration System Management

Most potentially hazardous situations occur during maintenance or system testing. During these phases, workers may access systems that interact or cause an interaction to potential hazards from other systems. In simple terms, changes in one system may affect another system. Because of these many complexities, NIF is operated under the Configured Systems Management Systems (CSMS) approach. Some of these managed systems of concern are:

- Laser Safety
- Fire Protection
- Radiation Shielding
- Argon System
- Liquid Nitrogen System
- Integrated Safety System (Interlock)
- Vacuum and Ventilation Systems

These systems are deemed critical in the safe and effective operation of the facility and thus, no changes can be made to any one system until they have been

approved by the Configured System Manager(s) (CSM) of the affected systems. For example, if one were to drill a hole through the target bay wall, this would affect the Laser Safety, Radiation Shielding, and Fire Protection Configured Systems. All of the individual system managers would have to approve of the work performed and ensure that the completed configuration met required specifications. Once this is completed, the CSM would inspect and sign off that the system meets the “as built” newly approved design requirements.



Configuration System Management

This method of control may be a departure or foreign to some in the realm of typical laboratory laser safety as the Laser Safety Officer (LSO) cannot freely make changes to the level of controls without approval through the Configured System Management System (CSMS). Items that are utilized for laser safety purposes become Configured Items (CI). Examples of these items are laser curtains, barriers, enclosures, procedures, etc. The CSM is responsible for specifying the requirements of these items.

CIs are owned by subsystem managers who are responsible for preventative maintenance, repair, and replacement of these items. The CIs must meet specifications approved by the CSM whether repaired, replaced, or modified. New drawings will be specified and created when CIs are modified or changed. These changes are reviewed and approved by the associated CSM.

As one of the many layers of laser safety, the CSMS is a necessity when dealing with a facility as large and complex as the NIF. Any changes, no matter how small, are controlled and managed through the CSMS where they are fully documented. Beyond the CSMS there are several other aspects to the program. They include Process Control, Work Permits, and a Laser Safety Working Group to name a few.

Aspects of the Program

Laser Safety at the NIF relies significantly on Engineering Controls. The main reasons for this are the size of the facility and diversity of staff. Engineering designs incorporate safety consideration from the on-set and remove many of the requirements that Administrative Controls bring, such as training. It also eliminates the chance of operator error brought about through procedural controls.

In general, R&D laser laboratory operations use a small and highly trained staff with an easily controlled operating space. Relying on Administrative Controls in this environment may be cost effective and thus more easily supported. At the NIF, each of the 192 beam lines are roughly 1500 meters in length and workers may require access into the areas for many different reasons. These workers may range from highly trained scientists, engineers, and technicians to maintenance personnel with minimal knowledge of lasers. When deciding between the use of engineered controls or procedural methods in this instance, the potential cost saving of using an administrative control is rarely worth the increase in risk.

Engineering Controls

When looking at the NIF as a whole, the first thing that stands out is that all beam lines are fully enclosed. This design was primarily for cleanliness concerns, but for the purpose of laser safety, a “light-tight” requirement was also implemented. This means that all covers, enclosures, and attachments are required to be installed with gaskets or utilize a “two-bounce” rule to mitigate diffuse scattered light. This ensures that personnel can work around an area where there may be an operating laser and not have to worry about the potential laser hazard within. It should be noted that all covers, enclosures, and attachments are required to be attached in such a way that a mechanical tool is required for their removal.

Another level of containment is compartmentalizing all operating areas. These main areas are the Laser Bays, Switchyards, Target Bay, and the Target Chamber. Access into these areas is controlled via the SIS. The SIS utilizes card-readers to limit access only to staff that are properly trained and authorized by management. This control is in place from the main entrance all the way into the Target Bay. Access requirements increase as you travel further into the facility. This means that there are significantly higher levels of training along with required access approval.

The SIS is also incorporated as an engineering control in other ways. They are:

- 1.) Key Sweeps- These are used to ensure that no personnel are left in an area that is required to be clear for a shot. A trained and qualified individual performs the sweep then turns a key upon exiting the area. This locks the SIS for that area into a “swept” or locked mode. If someone opens the door to any area that has been swept, the sweep is broken for all cleared areas.
- 2.) Permissives. A permissive is required in order to operate many of the lasers at the NIF. When a system is made up correctly, a permissive will permit that laser to fire. Permissives can also be controlled via “key trees” which will be described later.
- 3.) Information. Access controls are easily identified via text information and a multicolor-lighted bar. The text panel provides information and will turn the same color as the multicolor-lighted bar.
 - a. Green – area is safe for entry.
 - b. Amber – hazards may exist and only authorized personnel may enter.
 - c. Red – no access authorized.



SIS Panel

Laser Safety Working Group

All laser safety controls in place at the NIF are derived from a single body called the Laser Safety Working Group (LSWG). The LSWG is a committee that includes the LSO along with physicists and engineers

with backgrounds in lasers, optics, and safety. The LSWG's purpose is to evaluate modified and new lasers or systems added to the NIF. The LSWG reviews and determines what controls are to be implemented. This in-depth review is completed through a documented hazard's analysis. The completed analysis is captured in a document called a Laser Safety Gram (LSG).

Each analysis is very complex because it not only covers hazards presented from the proposed laser, but also hazards that exist from other NIF laser sources to personnel operating the proposed laser. In some cases, the hazards from the new laser may be negligible, but multiple controls may be required to protect the user from all outside optical hazards. Most hazard analyses on proposed new lasers may begin up to six months prior to installation because of the complexities involved.

The LSG is considered a guidance document which suggests all of the different options available, including both engineered and administrative controls. These controls are flowed into the OSP for the facility. This seven hundred plus page document covers the different controls that are required to be in place for various operating and maintenance situations. Beyond this main plan are extended policies and procedures that cover things such as energy isolation and sweeps.

Within the main body of the OSP are the descriptions for each different laser system and the hazards that are present from that specific laser. The Appendix of the OSP contains tables that cover laser hazards present from the facility to the worker in that specific area. These tables simply lay out the methods available to mitigate each of the hazards. Choice of mitigation must be completed in order to perform work in the different sections of the main laser system. In addition, there are tables covering external laser hazards that require mitigation in order for personnel to work on separate diagnostic laser systems throughout the facility.

Work Permits

Another level of control is the use of Work Permits (WP). WPs are used for any task that involves working on a component of the NIF. The WP describes the scope of the job, the workers involved, PPE, and approvals required. WPs are critical to ensure the status and readiness of the various systems throughout the NIF for operation. The WP process mirrors ISMS in function.

The work control process is coordinated through a single individual, the Work Control Officer (WCO). The OSP Appendix Tables described previously are used by the WP Responsible Individual (WPRI) to help determine the correct mitigation of laser hazards. These are verified by the LSO. An example of a table from the appendix is shown below. These hazard mitigations are listed in the “LOTO” section of the work permit.

Appendix E: Beampath Access/Entry Procedure (continued)

Table E.10.4 LCAL enclosure (port 77-54D) access/entry Hazard Mitigation Options Table
(Select at least one control option from each applicable row)
(2 pages) OSP 581.11-C46

Hazards Requiring Mitigation	Option 1	Option 2	Option 3	Option 4
1. PCS light All LB1 Bundles	LOTO all 12 SY1 RMDE gate valves closed	Target Chamber Access Key Tree	LOTO LCAL Gate Valve FV77_54D (Closed)	Note 2
All LB2 Bundles	LOTO all 12 SY2 RMDE gate valves closed	Target Chamber Access Key Tree	LOTO LCAL Gate Valve FV77_54D (Closed)	Note 2
2. PCU light All LB1 Bundles	LOTO all 12 SY1 RMDE gate valves closed	Target Chamber Access Key Tree	LOTO LCAL Gate Valve FV77_54D (Closed)	Note 2
All LB2 Bundles	LOTO all 12 SY2 RMDE gate valves closed	Target Chamber Access Key Tree	LOTO LCAL Gate Valve FV77_54D (Closed)	Note 2
3. Regen*	LOTO all 24 SY1 & SY2 RMDE Gate Valves closed	1x CO 7 Eyewear	LOTO LCAL Gate Valve FV77_54D (Closed)	Note 2
4. LM113 1x LS*	LOTO all 24 SY1 & SY2 RMDE Gate Valves closed	1x CO 7 Eyewear	LOTO LCAL Gate Valve FV77_54D (Closed)	Note 2
5. ISP 1x *	LOTO all 24 SY1 & SY2 RMDE Gate Valves closed	1x CO 7 Eyewear	LOTO LCAL Gate Valve FV77_54D (Closed)	Note 2
6. TSF 1x or TSF Ref*	LOTO all 24 SY1 & SY2 RMDE Gate Valves closed	1x CO 7 Eyewear	LOTO LCAL Gate Valve FV77_54D (Closed)	Note 2
7. TSF 3x	N/A			
8. POS 1x	N/A			
9. VISAR	Target Chamber Access Key Tree	LOTO VISAR manual shutter (closed) OR LOTO VISAR Interferometer Guideline safety shutter (closed)	LOTO VISAR probe laser power supplies (off)	LOTO LCAL Gate Valve FV77_54D (Closed) Note 2 OR LOTO DM 90-315 GV (closed)

Laser Hazard Mitigation Table

Lock-out Tag-out

A control measure used at the NIF, not normally found in typical laser laboratories is lock-out-tag-out (LOTO). Most laser laboratories are under the control of a single or a limited number of individuals. This group is “knowledgeable” to the potential hazards that exist in their space and they can easily contain or control the laser hazards within the four walls.

ANSI Z136.1 calls for the use of a master key to be used in Class 4 lasers, but does not mention LOTO. This presents a huge safety gap, especially where laser hazards cannot be easily contained in a single space. While LOTO may not work well or may not be feasible for laser operations in individual laboratories, it is well suited for those operations within the NIF.

Within the NIF there are workers operating or performing maintenance on various systems at any one time. Many of these systems interact, overlap, and involve the use of numerous and various high-powered lasers. Because of this, strict controls must be put in place for personnel safety. A laser operator may be ready to use his/her laser, but because of the complexities involved, they would not know if the beam path was clear of personnel without a strict process in place. This is where the use of LOTO and Work Permits serves a very important role.

To authorize execution of a WP, the WCO uses the OSP Appendix Tables to verify and approve the method of control for their task. If it is determined that LOTO is required, and the WP is released for work, the Energy Owner (EO) applies their lock to the laser shutter or power supply and places that key in the LOTO box. If setting up a Group LOTO, the EO would apply another lock to the LOTO lock box. The key to the lock box remains with that person. A verifier checks the LOTO to ensure it was performed correctly. All additional personnel performing work under the WP would then apply their Personal LOTO lock to the lock box.

When a worker completes the approved task, they close out the WP and clear their Personal LOTO. As each job is completed, those locks are removed until all workers LOTOs have been cleared and associated locks removed. The EO is the final person to remove their lock and clear the LOTO at the source (power supply or shutter). The laser is now ready to be used.



Worker applying group LOTO

Key Trees

Another method to control hazardous laser light at the NIF is the use of Key Trees. As discussed previously, the ANSI Z136.1 does not point out energy isolation for high-powered laser hazards beyond the use of a master key switch. In the construction of the NIF it was decided that relying on this mode of control alone was not enough. All high-powered lasers are required to either be able to be LOTO'd or to electronically remove their ability to fire. The latter was approved by the Department of Energy (DOE) to be used specifically for laser hazards. This method of control is called Key Trees.

These non-LOTO'd high-powered lasers are connected to the SIS and, as such, they can be controlled electronically through the Key Trees. Where LOTO

removes the energy source from the laser, a Key Tree removes “permissives” for the laser to operate. If the Key Tree is set to “Disable”, the permissives for the laser are removed and the laser cannot fire. The overall system is very similar in function, but is separate to LOTO. With a Key Tree, a worker turns the key to “Disable” and then removes it. The key is placed in the Key Tree Lock Box and the worker applies their “Administrative” lock to the lock box. Each additional worker would apply their lock to the lock box

An Administrative lock is different in color and use than that of a LOTO lock. Any worker choosing this method of control, from the OSP Appendix Table, would also apply their lock to the lock box. An example of a Key Tree is shown in the photograph below:



NIF Key Tree

Safe Plan of Action

Finally, the last piece of the puzzle before work can be conducted is the Safe Plan of Action or (SPA) Meeting. These are team meetings that are held with a Daily Work Team Leader (DWTL) to inform the workers of the hazards that may exist at the work location. These meetings are very important, especially for a large facility with ever changing hazards. The SPA also serves as an opportunity for the DWTL to verify that the correct PPE is available and worn. This is also a final opportunity to solicit feedback and ensure that the workers are fit and able to work.

Summary

As described in this paper, within the NIF there is no single source barrier allowed to be used to protect personnel from high powered laser hazards. The multi-layered or Defense-in-Depth approach is used

throughout the NIF to ensure that worker safety is first and foremost. With the fundamental belief that all accidents are preventable, the NIF is operated with a philosophy that you cannot have a world class research facility without a first class safety program. They must go hand-in-hand. Through the Defense-in-Depth approach, the NIF has both.

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Meet the Author

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